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Analysis of Precipitation Trends and Prediction in Selected Cities in the Southeast Louisiana

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Abstract

The impacts of climate change are being felt in Louisiana, in the form of changing weather patterns that have resulted in changes in floods, hurricanes, tornadoes frequencies of occurrence, and magnitudes, among others resulting in, flooding. The variabilities in rainfall in a drainage basin affect water availability and sustainability. This study analyzed the precipitation data of Southeastern Louisiana, United States, for the period 1990 to 2020. Data used in the study was from, Donaldsonville, Galliano, Lafourche, Gonzales, Ascension, Morgan, New Orleans, Audubon, Plaquemine, and Ponchatoula, Tangipahoa, weather stations. These stations were selected because the differences between each of their highest and lowest average annual rainfall data were greater than 20 inches. To investigate climate patterns and trends for the given weather stations in Southeastern Louisiana, precipitation data were analyzed on annual time scales using data collected from the World Bank Group Climate Change Knowledge Portal for Development Practitioners and Policy Makers and the Applied Climate Information System (ACIS) of the National Weather Service Prediction Center. The data were further aggregated using annual average blocks of 4 years, and linear and polynomial regression was performed to establish trends. The highest and lowest average annual rainfall data for Donaldsonville, Galliano, Lafourche, Gonzales, Ascension, Morgan, New Orleans, Audubon, Plaquemine, and Ponchatoula, Tangipahoa, weather stations were, 75 and 48, 71 and 44, 73.5 and 52.7, 75 and 46.4, 72 and 41.3, 94 and 55.3, Ponchatoula, and 78.6 and 44, respectively. Plaquemine recorded the highest average annual average rainfall while New Orleans, Audubon station recorded the lowest. The projection of the precipitation in 2030 has been carried out to inform scientists and stakeholders about the approximate quantity of rainfall expected and enable them to make their expected impacts on agriculture, economy, etc. The precipitation for 2030 was predicted by extrapolating models for the weather stations. The data used for the modeling was selected based on the data entries most representative. Hence, the coefficient of correlation and the number of data entries were both considered. Extrapolating results for 2030 precipitation in Donaldsonville, Galliano, Gonzales, Morgan, New Orleans, Audubon, and Plaquemine were found to be within the ranges, (85.6 - 86.7), (75.55 - 76.60), (89.7 - 90.67), (99.9 - 100.5), (71.68 - 72.66), and (107.7 - 108.8) inches, respectively. Hence, the average annual precipitations in areas covered by these stations except for Plaquemine station are expected to significantly increase. A restively low increase in average precipitation is expected for Plaquemine station. The increase could impact agriculture negatively or positively depending on the crop's soil moisture tolerance.

Keywords

Precipitation, Linear and Polynomial Regression, Extrapolating Models, Southeastern Louisiana

1. Introduction

Climate is one of the important drivers of ecosystems' health, compositions, and other earth systems [1]. That is, the impact of climatic conditions over the earth's surface and its variations has the propensity to affect certain areas such as agriculture, public health, water supplies, energy production and use, land use, and development, as well as recreational activities. The climatic fluctuations usually determine the average weather and climate conditions over a period, characterized by variable factors including rainfall, temperature, atmospheric pressure, and humidity. These variations are also attributed to changes in greenhouse gases and aerosols, which are expected to result in regional and global changes in temperature, precipitation, and other climate variables, leading to global changes in soil moisture, global mean sea level, and occurrence of more severe extreme high-temperature events, floods, and droughts in some places [2]-[10].

Considering that the subject of climate change is vast, there is at least one topic within this subject that deserves urgent and systematic attention, and that is the changing pattern of precipitation around the world [11]. Precipitation is considered one of the most important variables for climate and hydrometeorology by which a change in its pattern may lead to floods, droughts, loss of biodiversity, and agricultural productivity [12]. Remarkably, global changes especially the warming of the earth's surface, are gradually influencing regional climates, especially rainfall patterns. For instance, there have been considerable spatial and temporal variations that have occurred over the past 100 years, and notably, these tendencies of warming and increased precipitation have not been globally uniform [13]. Another example is cited by [12], whereby climate change studies have also demonstrated that the land-surface precipitation shows an increase of 0.5% - 1% per decade in most of the Northern Hemisphere mid and high latitudes, and the annual average of regional precipitation increased 7% - 12% for the areas in 30˚N - 85˚N and by about 2% for the areas 0˚S - 55˚S over the 20th century.

More so, concerns have been raised about the impacts of climate change which has heightened the need for accurate information about spatial and temporal variations in precipitation over the Earth's surface [14]. That is, as the earth warms, it causes changes in temperature, rainfall, and other patterns of weather and climate, hence, posing threats to human health [15], plant, and animal lives. To further examine this phenomenon, [1] cited [16] about research carried out an analysis of monthly temperature and precipitation time series for hundreds of weather stations across Canada whereby variations in temperature and precipitation at different temporal and spatial scales were discovered [16]. Therefore concluded that, the differences observed in temperature and precipitation could have been influenced by the variations in atmospheric circulations.

Additionally, the variations of the climate in terms of temperature and precipitation have been examined in different regions of the world over recent decades [17] [18] [19] [20] [21]. This is because clearly, increasing global surface temperatures are very likely to lead to changes in precipitation and atmospheric moisture because of changes in atmospheric movement, a more active hydrological cycle, and increases in the water-holding capacity throughout the atmosphere [11]. Other examinations on understanding this pattern revealed that, variations in precipitation trends and distributions are observed in the Northern and Southern hemispheres due to the physical distribution of more landmass in the North than in the South, thereby inducing a greater thermal effect in the North than in the South [11].

Based on this, it is prudent to discuss the dynamics of precipitation over the earth's surface as well as its trends in order to make predictions over a period of time. Agreeably, the ability to identify precipitation trends and predict future precipitation values is very important for both industrial and individual purposes [22]. Hence, this study examines rainfall data in Southern Louisiana to determine the precipitation trends and patterns in certain selected cities. This will be done by identifying the factors that are influencing precipitation trends and the shift in precipitation patterns that may impact future predictions. The analyses will mainly be conducted on Southeastern Louisiana's coastal counties to analyze rainfall patterns as well as temperature. By the end of this study, it is expected that the findings of this research will establish more insights in relation to understanding the hydrologic behavior over the last three decades in Southeastern Louisiana.

2. Methodology

Data Acquisition and Processing

For this study, the coastal counties of Southeastern Louisiana coastal counties were selected for temporal analysis of rainfall. Rainfall data for 1990-2020 or the available range of years for the selected parishes (**Figure 1**) was downloaded from the World Bank Group Climate Change Knowledge Portal for Development Practitioners and Policy Makers [23] and the Applied Climate Information System (ACIS) of the National Weather Service Prediction Center [24]. The monthly rainfall data from Donaldsonville, LA weather station for the years, 1990-2020, was used. It is presented in **Tables 1-4**, respectively. Annual rainfall values were computed for years that had some monthly rainfall data missing (2008, 2015, and 2016, respectively).

A table for the annual rainfall data in inches versus corresponding years was prepared by extracting years and corresponding annual rainfall data from **Tables 1-4**, respectively. The data is presented in **Table 5** and **Table 6**, respectively.

Data was then prepared for modeling using the approach by [1]. The average rainfall data for each 4-year blocks was summed up and then divided by 4 to yield the average annual precipitation data, based on 4 years (aggregation of data using batches of 4 years). To illustrate the computation, **Tables 7-10**, etc. were extracted from the 1990-2020 rainfall data.

The 1990-2020 Donaldsonville's annual mean rainfall data based on 4-year blocks for was then compiled using the computed means from **Table 7**, **Table 8**, etc. and presented in **Table 11**.

The procedure for preparing data for Donaldsonville's average annual rainfall

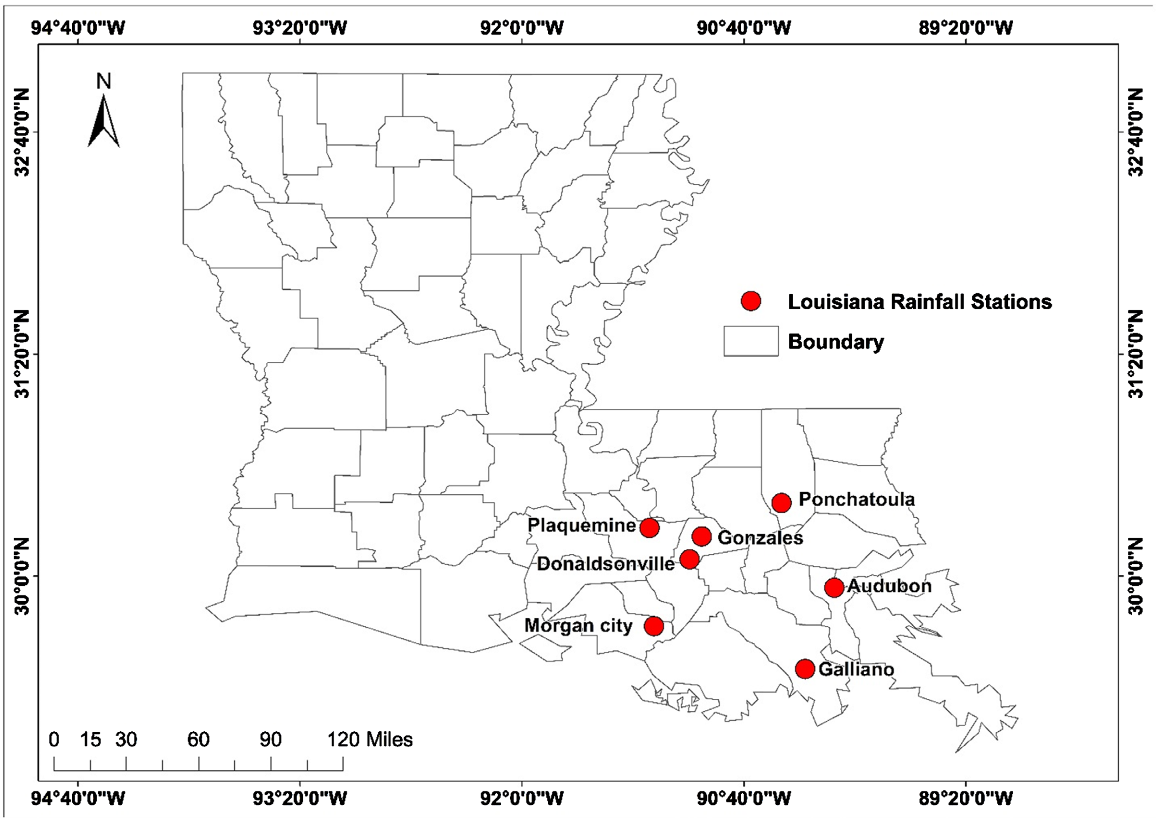

Figure 1. Location of the study area.

Table 1. The monthly rainfall data from Donaldsonville in inches (1990-1998).

Year	1990	1991	1992	1993	1994	1995	1996	1997	1998
Jan	6.42	12.35	15.57	7.62	4.03	4.73	3.5	5.38	18.86
Feb	7.51	4.88	9.65	2.8	1.31	1.81	1.49	5.99	4.82
Mar	10.63	4.29	3.38	4.7	2.44	13.49	2.29	2.43	4.62
Apr	3.67	15.27	5.27	10.93	5.22	6.02	2.86	6.96	2.31
May	3.24	19.15	3.67	3.66	3.79	8.96	1.69	8.33	
Jun	4.89	3.99	8.49	8.13	4.96	2.8	4.81	10.63	2.69
Jul	4.51	5.47	10.81	7.67	10.69	4.74	5.8	7.9	4.54
Aug	5.25	3.75	11.82	2.46	1.69	4.61	8.56	2.35	3.69
Sept	2	9.51	2.22	3.15	6.23	2.89	3.26	1.51	15.75
Oct	2.84	4.23	2.04	5.45	2.69	6.32	11.35	2.68	3.29
Nov	4.21	2.12	11.67	3.12	1.92	7.42	3.49	5.67	2.46
Dec	5.62	1.15	4.91	3.74	3.06	3.44	6.36	3.45	2.05
Annual	60.79	86.16	89.5	63.43	48.03	67.23	55.46	63.28	65.08

Table 2. The monthly rainfall data from Donaldsonville in inches (1999-2007).

Year	1999	2000	2001	2002	2003	2004	2005	2006	2007
Jan	4.66	2.95	4.65	3.97	0.44	2.98	2.71	2.51	6.48
Feb	1.64	0.62	2.48	1.44	5.82	11.44	6.91	3.41	1.08
Mar	3.33	4.59	10.84	6.1	1.9	1.07	1.94	0.5	2.07
Apr	0.75	0.41	1.29	4.51	10.53	5.97	1.81	4.38	3.62
May	3.8	0.33	1.3	0.84	0.01	12.4	5.62	0.85	7.28
Jun	8.25	5.54	24.26	9.64	10.92	8.87	5.11	0.47	7.7
Jul	5.79	1.6	5.85	6.14	9.17	9.39	6.54	5.63	7.44
Aug	2.18	4.35	6.93	5.16	4.06	3.61	7.64	7.7	2.01
Sept	4.36	6.5	3.04	8.67	3.06	1.94	4.78	3.73	6.67
Oct	8.84	0.84	5.29	12.95	3.86	8.98	0	7.6	3.91
Nov	1.06	14.01	1	6.46	6.79	8.03	1.71	3.86	1.04
Dec	4.91	2.34	2.31	7.1	2.77	1.88	3.79	12.86	4.7
Annual	49.57	44.08	69.24	72.98	59.33	76.56	48.56	53.5	54

Table 3. The monthly rainfall data from Donaldsonville in inches (2008-2016).

Year	2008	2009	2010	2011	2012	2013	2014	2015	2016
Jan	0	4.13	2.79	4.09	2.33	13.49	2.13	4.99	3.63
Feb	2.89	1.55	7.23	1.67	5.57	8.01	5.2	2.51	6.68
Mar	2.35	5.93	2.08	5.08	8.32	0.44	2.46	4.18	0

Continued

Apr	2.21	3.84	0.3	0.91	6.05	5.29	3.5	0	3.72
May	6.5	5.22	3.41	0.19	1.9	8.26	18.36	5.69	8.39
Jun	3.92	3.95	6.17	6.03	7.23	3.17	6.14	8.08	8.49
Jul	2.6	6	8.07	5.77	6.1	5.58	6.61	5.2	8.52
Aug	8.67	4.05	9.94	2.69	15.8	8.38	3.89	1.78	22.06
Sept	0	9.1	4.15	10.72	5.02	4.4	10.74	3.58	4.49
Oct	0.13	12.66	1.53	0.43	0.35	2.83	2.84	8.91	0.33
Nov	2.38	0.97	6.99	2.7	1.97	2.33	2.38	9.79	2.28
Dec	3.92	15.74	2.73	2.87	3.42	3.01	5.28	8.74	5.5
Annual	35.57	73.14	55.39	43.15	64.06	65.19	69.53	63.45	74.09

Table 4. The monthly rainfall data from Donaldsonville in inches (2017-2021).

Year	2017	2018	2019	2020
Jan	10.99	6.79	3.11	5.73
Feb	1.71	4.98	4.03	3.73
Mar	3.09	3.37	2.57	1.9
Apr	2.09	7.05	6.75	4.22
May	13.75	1.39	4.95	9.45
Jun	12.15	4	5.45	6.9
Jul	5.73	2.52	8.03	9.4
Aug	10.6	9.02	7.19	4.49
Sept	1.52	7.04	0.38	3.9
Oct	2.15	3.96	7.91	5.25
Nov	1	6.09	1.39	4.26
Dec	7.41	10.33	2.68	3.81
Annual	72.19	66.54	54.44	63.04

Table 5. The annual rainfall data in inches for Donaldsonville for the period 1990-2005.

Year	Annual average rainfall (1990-2005)
1990	60.79
1991	86.16
1992	89.5
1993	63.43
1994	48.03
1995	67.23
1996	55.46

Continued

1997	63.28
1998	65.08
1999	49.57
2000	44.08
2001	69.24
2002	72.98
2003	59.33
2004	76.56
2005	48.56

Table 6. The annual rainfall data in inches for Donaldsonville for the period 2006-2020.

Year	Annual average rainfall (2006-2020)
2006	53.5
2007	54
2008	35.57
2009	73.14
2010	55.39
2011	43.15
2012	64.06
2013	65.19
2014	69.53
2015	63.45
2016	74.09
2017	72.19
2018	66.54
2019	54.44
2020	63.04

Table 7. Computation of average mean rainfall based on 4-year blocks for 1990-1993.

Year	Annual precipitation
1990	60.79
1991	86.16
1992	89.5
1993	63.43
1990-1993 Average	74.97

Table 8. Computation of average mean rainfall based on 4-year blocks for 1993-1996.

Year	Annual precipitation
1993	63.43
1994	48.03
1995	67.23
1996	55.46
1993-1996 Average	58.5375

Table 9. Computation of average mean rainfall based on 4-year blocks for 1996-1999.

Year	Annual precipitation
1996	55.46
1997	63.28
1998	65.08
1999	49.57
1996-1999 Average	58.3475

Table 10. Computation of average mean rainfall based on 4-year blocks for 1999-2002.

Year	Annual precipitation
1999	49.57
2000	44.08
2001	69.24
2002	72.98
1999-2002 Average	58.9675

Table 11. Donaldsonville's average annual rainfall in (based on 4-year blocks).

Year	Annual
1990	60.79
1993	74.97
1996	58.5375
1999	58.3475
2002	58.9675
2005	64.3575
2008	47.9075
2011	51.8125
2014	60.4825
2017	69.815
2020	64.0525

data based on 4 consecutive years was also applied for determination of corresponding rainfall for, Galliano, Lafourche, Gonzales, Ascension, Morgan, New Orleans, Audubon, Plaquemine, Ponchatoula, Tangipahoa, respectively.

To model the associations between variables in this study, regression analysis through curve and line fitting was used. Models for mean rainfall based on data sets of mainly 4 consecutive years were modeled based on the following respective formulations.

$$\text{Rainfall,} \quad R = f(t)$$

where $f(t)$ represents a function of time, in years. Hence, rainfall, *R*, is a function of time.

For the general polynomial model,

$$R = A_n t^n + A_{n-1} t^{n-1} + \cdots + A_0 t^0 \tag{1}$$

For cubic model,

$$R = A_3 t^3 + A_2 t^2 + A_1 t + A_0 \tag{2}$$

For quadratic model,

$$R = A_2 t^2 + A_1 t + A_0 \tag{3}$$

For linear model,

$$R = A_1 t + A_0 . \tag{4}$$

R is the average rainfall based on 4 consecutive years in mm/year, *n* is the polynomial index and t is time in years. A_n, A_{n-1}, A_{n-2}, ..., A_2, A_1 and A_0, are constants.

Statistical software (SPSS, Microsoft Excel data analysis toolkit, etc.) was used to fit data and build models. The strength of model developed was based on the magnitude of the coefficients of correlations between variables (r square), which ranged from 0 to 1.0 (0% - 100%).

A model was adopted if its coefficient of correlation was close to 100%. Linear and curvilinear curve fitting was applied depending on the associations between data pairs, which attempts to develop single models for data sets spanning from 1901 to 2020 yielded models of low coefficients of correlations for most data sets. To develop models that were more representative of the data sets, illustrating the rises and falls in environmental data, data aggregates from time spans shorter than the entire data collection range of time (1901-2020) were used in modeling. Models for rainfall trends were carried out for data sets from 7 selected weather stations. The modeling concept is illustrated in Figure 2.

3. Results and Discussion

Correlations between all possible pairs of data were carried out using Microsoft Excel. The results are presented in Table 5. Separate regression models had to be modeled for each station. The only strong correlations found between data pairs were between, Gonzales and Donaldsonville, and Morgan City and Donaldsonville,

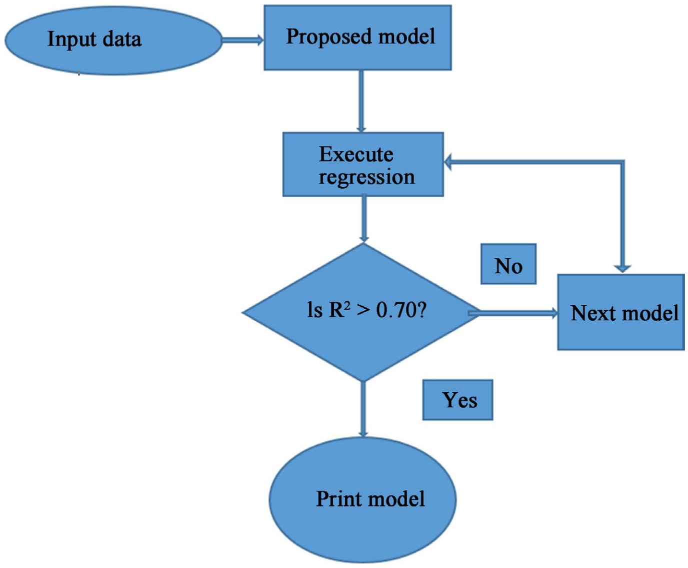

Figure 2. The modeling concept for rainfall.

Table 12. Correlation matrix for stations' precipitation data.

	Donaldsonville	*Galliano*	*Gonzales*	*Morgan City*	*New Orleans Audubon*	*Plaquemine*	*Ponchatoula*
Donaldsonville	1						
Galliano	0.500135767	1					
Gonzales	0.764244207	0.687749	1				
Morgan City	0.888731725	0.479083	0.799872	1			
New Orleans Audubon	0.396405375	0.776659	0.254781	0.24830782	1		
Plaquemine	0.599027839	-0.1009	0.594578	0.64250353	-0.327612971	1	
Ponchatoula	0.471453147	-0.05326	0.159556	0.54995264	-0.112734192	0.37182632	1

Gonzales and Morgan City, and Galliano and New Orleans Audubon, as shown in the following correlation matrix (**Table 12**). Hence, different, using separately derived, regression coefficients for each individual station are not a methodologically misguided approach. It is evident from the correlation matrix that some data pairs are negatively correlated, and the magnitudes of correlations vary significantly.

A cubic model was used to fit Donaldsonville's average annual rainfall data, based on 4-year blocks for the period 1990-2002. With R^2 of approximately 0.73, the model represented about 73% of the data's variation (**Figure 3**). During this period, the mean annual rainfall/4 years rose from 60 in 1990 to 70 inches in 2002 and then decreased according to the model to just below 60in. The model is represented as follows,

$$y = 0.097x^3 - 580x^2 + 1E + 06x - 8E + 0824.58, \; R^2 = 0.72$$

Donaldsonville's average annual rainfall data for 2002-2011 was fitted to a cubic polynomial model. The model is given as, $y = -0.260x^3 - 1567.9x^2 + 3E + 06x - 2E + 09$, with $R^2 = 1$. Hence, this model explains about 100% of the variation of the data. From 2002 to 2004, the average precipitation rose from 60 in to approximately 68 inches, just before 2004. It then dropped gradually to about 45 inches in 2009 and rose to 52 inches in 2011 (Figure 4).

Donaldsonville's average annual rainfall data for 2011-2020 was fitted to a second order polynomial model. The model is given as, y= −0.4009x^2 + 1617.6x − 2E + 06, with R^2 = 0.927 (Figure 5).

The model explains about 97.3% of the variation in the data. The data increases according to the model from about 62 inches to about 68 inches and then decreases to about 65 inches in 2020.

Prediction for Donaldsonville's average annual rainfall for 2030 was carried out by extrapolation of the model that final general trend (2008-2020). The predicted annual average rainfall was about 85.6 - 86.7 inches (Figure 6).

The model explains 79% of the field data.

The mean of annual rainfall for Galliano (1990-2019) per 4-year basis presented in Table 13.

The rainfall data for Galliano, Lafourche for the time range 1990-2019 was fitted to a quadratic model illustrated in Figure 7.

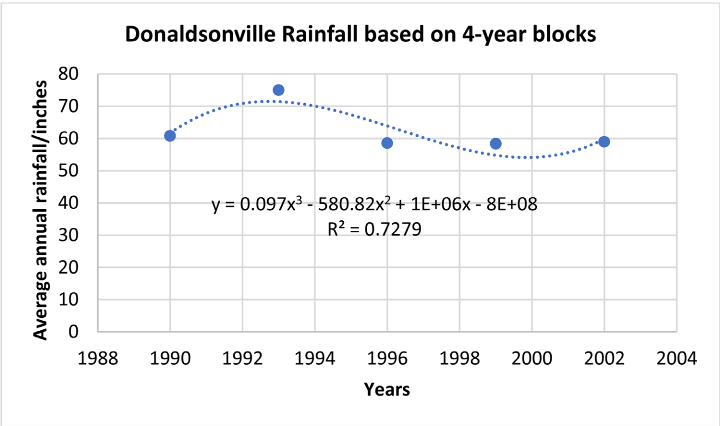

Figure 3. Donaldsonville's average annual rainfall data, based on 4-year blocks for the period 1990-2002.

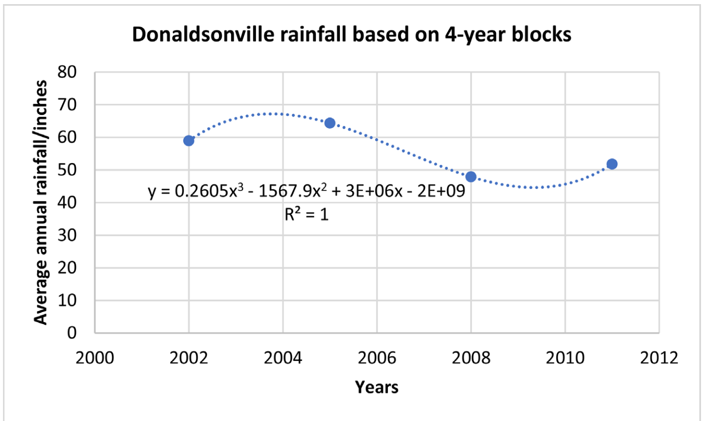

Figure 4. Donaldsonville's average annual rainfall data, based on 4-year blocks for the period 2002-2011.

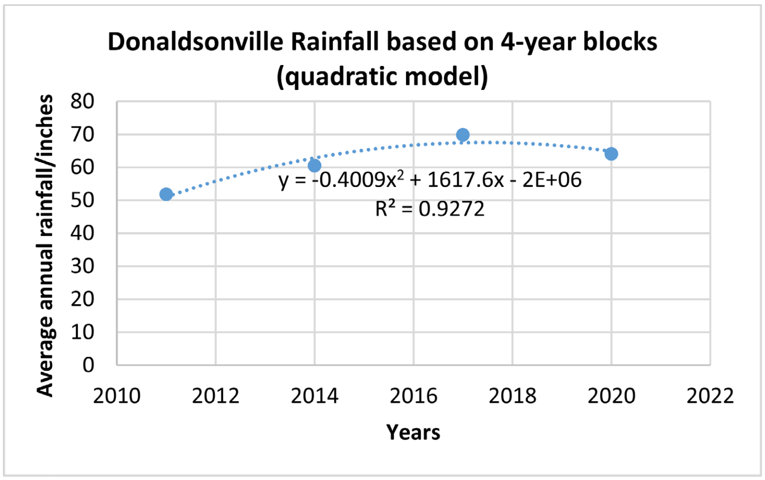

Figure 5. Donaldsonville's average annual rainfall data, based on 4-year blocks for the period 2011-2020.

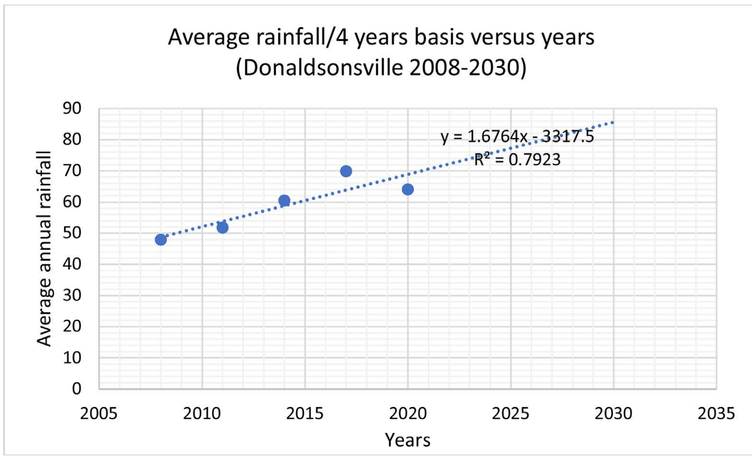

Figure 6. Model for average annual rainfall for Donaldsonville (2008-2030).

Table 13. Mean of annual rainfall per 4-year basis for Galliano (1990-2019).

Year	Average annual precipitation/4 years
1990	49.93
1993	71.0675
1996	60.4775
1999	61.4375
2002	58.8425
2005	62.1225
2008	54.8325
2011	48.345
2014	44.0425
2017	54.2475
2019	53.24667

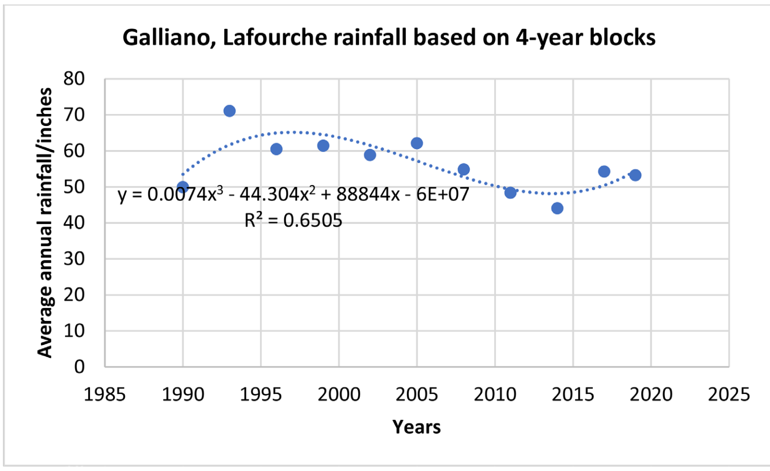

Figure 7. Galliano, Lafourche's average annual rainfall data, based on 4-year blocks for the period 1990-2019.

The model suggests that precipitation for Galliano rose from 50 inches to approximately 65 inches between 1995 and 2000, and then dropped gradually few inches below 50 inches between 2010 and 2015, and then rose gradually to a magnitude to approximately 52 inches.

The model represents about 65% of the climate data.

Stronger models were developed by fitting data from, 1990 to 2005, and 2005 to 2019 to two models, respectively. The models are illustrated in Figure 8 and Figure 9, respectively.

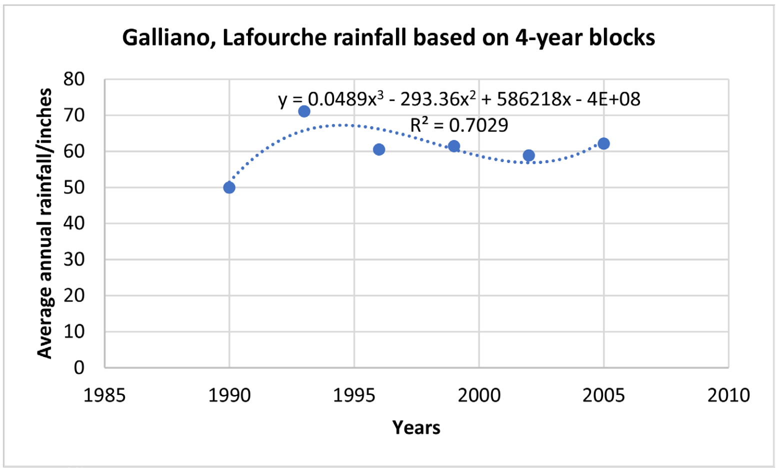

Figure 8. Galliano, Lafourche's average annual rainfall data, based on 4-year blocks for the period 1990-2005.

The model suggests that the average rainfall increased cubically from 50 inches in 1990 to almost 70 inches in 1994 and then decreased to settle abbot 60 inches in 2005.

Modeling of 2005-2019 annual means' data produced the following graph Figure 8. The coefficient of correlation for the model is about 84%. The model explains 84% of the data's variation.

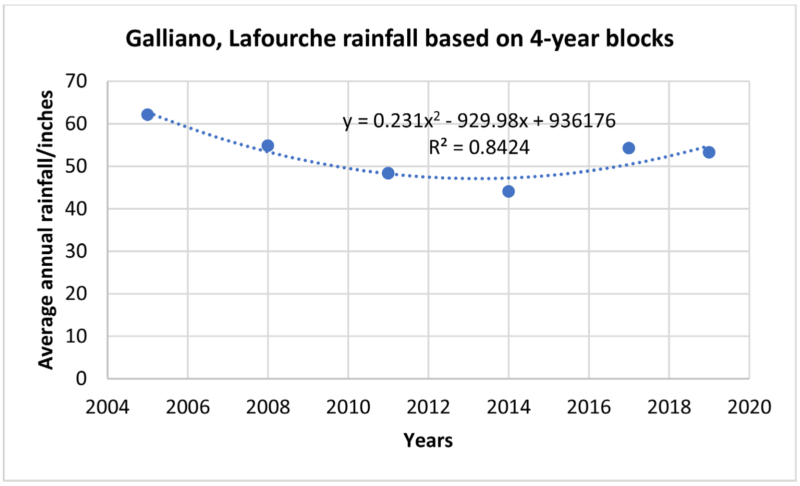

Figure 9. Annual mean rainfall data per 4-year basis for Galliano, Lafourche for the time range 2005-2019.

The coefficient of correlation for the quadratic model is about 84%, and hence, the model represents 84% of the data's variation. The model suggests that the average annual rainfall/4-year basis decreased from 63 inches to a minimum of between 45 and 50 inches and then increased to settle just below 55 inches.

Galliano's data is strongly positively correlated to that of New Orleans Audubon. Galliano's and New Orleans, Audubon's elevations above the sea level are,3 ft (0.9 m), and 3 feet (0.91 m), and 4 feet (1.2 m), and both are close to large water bodies. Hence, the climatic patterns are strongly correlated. Since the precipitation of New Orleans, Audubon area generally increased from 2014 to 2020, the precipitation of Galliano is also assumed to have generally increased. A linear model fitting of Galliano's data for 2014-2019 using Microsoft Excel yielded a model of positive slope. This model was extrapolated to estimate the precipitation in 2030 (**Figure 10**).

The predicted average precipitation for Galliano, Lafourche for 2030 is 75.56 - 76.58 inches.

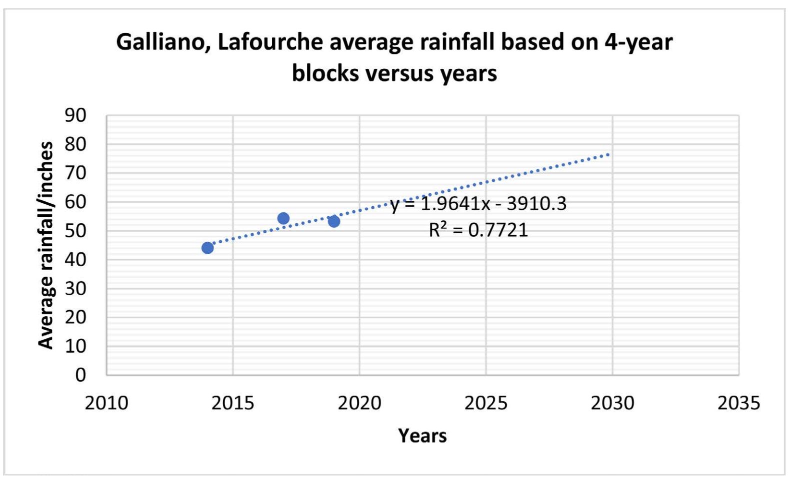

Figure 10. Galliano, Lafourche, model of rainfall versus years, 2014-2030.

3.1. Gonzales, Ascension Parish

The average annual rainfall data/4 years for Gonzales, Ascension is presented in Table 14.

A cubic function was used in fitting the whole data (1990-2020). It is presented in Figure 11.

The mode's R^2 value is about 63% and hence, represents about 63% of the data. Models that present larger proportions of the variations in the data were constructed using shorter spans of time as follows. The data for 1990-2005 was modeled by curve fitting to a cubic function. It is presented in Figure 12. The mode's R^2 value is about 94.45% and hence, represents about 94% of the data. The rainfall/4 years rose from 54 inches in 1990 to 70 inches in 1993. It then decreased to just below 60 inches in 2002 and then rose to just above 60 inches in 2005.

The data for 2005-2020 was modeled by curve fitting to a cubic function. It is presented in Figure 13. The model's R^2 value is about 82.7% and hence, represents

Table 14. The average annual rainfall data/4 years for Gonzales, Ascension.

Year	Average annual precipitation/4 years
1990	53.89
1993	71.25
1996	**67.64**
1999	63.2525
2002	59.7475
2005	62.0425
2008	52.1575
2011	53.04
2014	52.7425
2017	73.5375
2020	70.5825

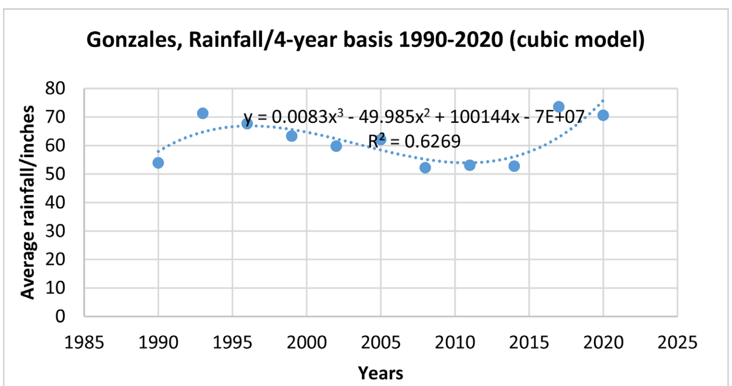

Figure 11. The average annual rainfall data/4-year versus years for Gonzales, Ascension.

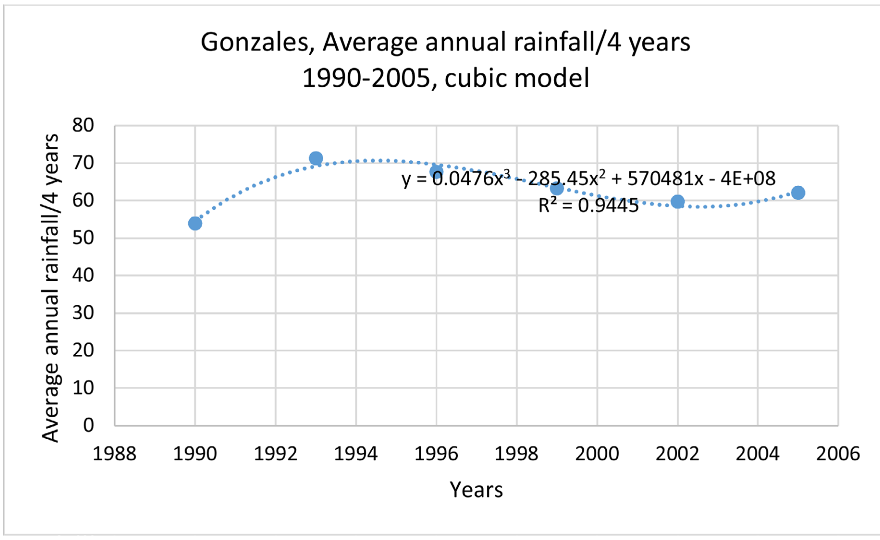

Figure 12. Average annual rainfall/4-year data for Gonzales, Ascension (1990-2005).

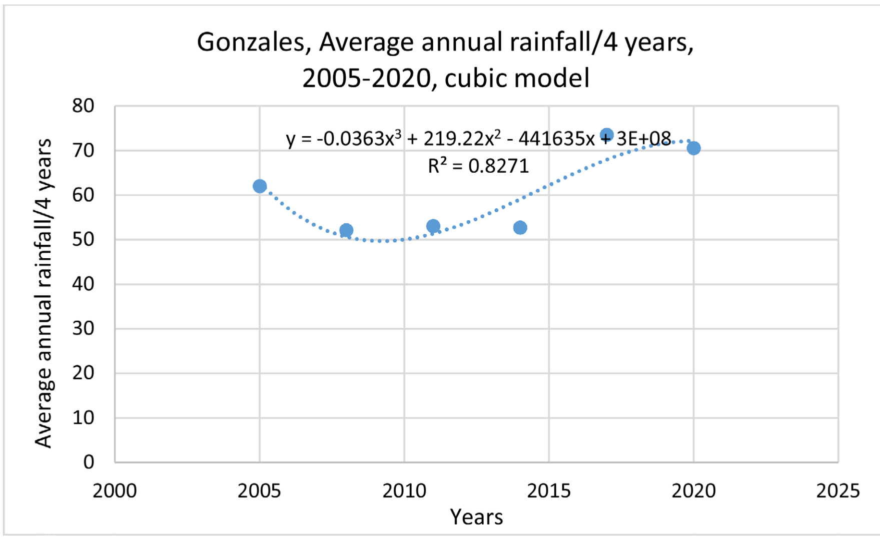

Figure 13. Average annual rainfall/4-year data for Gonzales, Ascension (2005-2020).

about 82.7% of the data.

In the span of rime (2005-2020), the average annual rainfall/4 years' data for Gonzales dropped from 62 inches 2005 to 50 inches between 2008 and 2010 and then gradually increased to a maximum of approximately 70.5 inches in 2020.

Prediction for Gonzales, Ascension's average annual rainfall for 2030 was carried out by extrapolation of the model that final general trend (2008-2020). The predicted annual average rainfall was about 89.7 - 90.67 inches (**Figure 14**). The model explains 72% of the field data.

3.2. Morgan City Rainfall

The average annual rainfall for Morgan, based on 4-year blocks is presented in **Table 15**.

Rainfall data for Morgan for 1990-2017 was modeled using a cubic function,

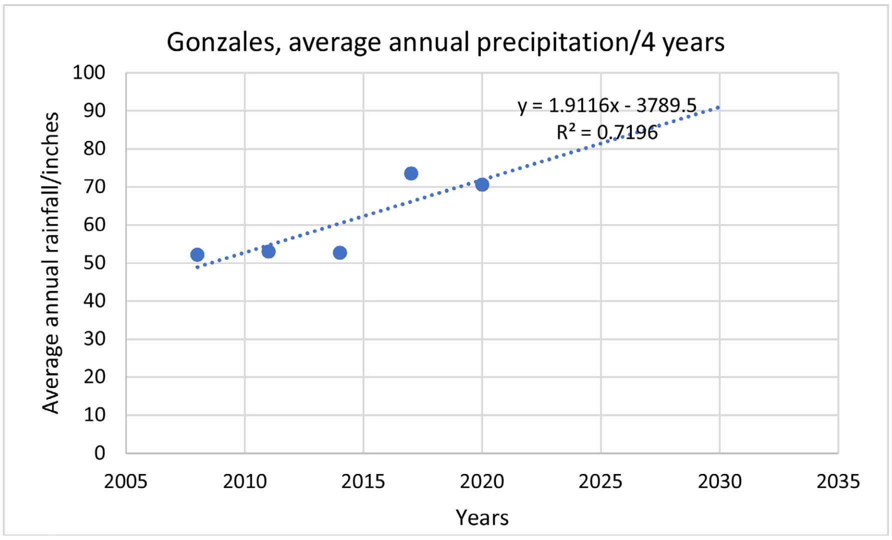

Figure 14. Model for average annual rainfall for Gonzales, Ascension's (2008-2030).

Table 15. The average annual rainfall for Morgan, per 4 years.

Year	Annual
1990	55.47
1993	74.905
1996	57.26
1999	57.76
2002	56.365
2005	50.9875
2008	47.595
2011	46.3925
2014	57.62909
2017	69.82409

illustrated in **Figure 15**. The coefficient of correlation for the model was about 74% and hence, it explained approximately 74% of the data's variation. The average rainfall rose from approximately 60 inches in 1990 to approximately 65 inches in 1995. It then decreased according to the cubic model to a minimum quantity which is just less than 50 inches. Then average rainfall then gradually increased to 70 inches in 2019 (**Figure 15**).

Stronger models were developed by carrying out piecewise modeling. A model for the time span 1990-1999 was developed by fitting the data to a cubic function as presented in **Figure 16**. Its coefficient of correlation is 100%. Hence, the model represents about 100% of the data's variation. According to the model, precipitation rose from about 55 inches in 1990 to approximately 75 inches just before 1993. It then dropped to approximately 50 in between 1996 and 1999 and then rose to approximately 58 inches in 1999.

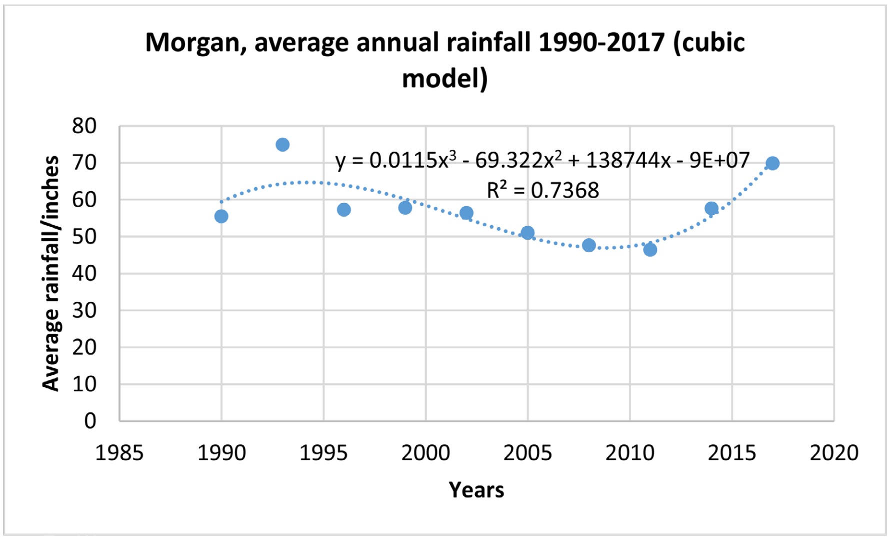

Figure 15. Morgan, average annual rainfall data on 4-year basis (1990-2017).

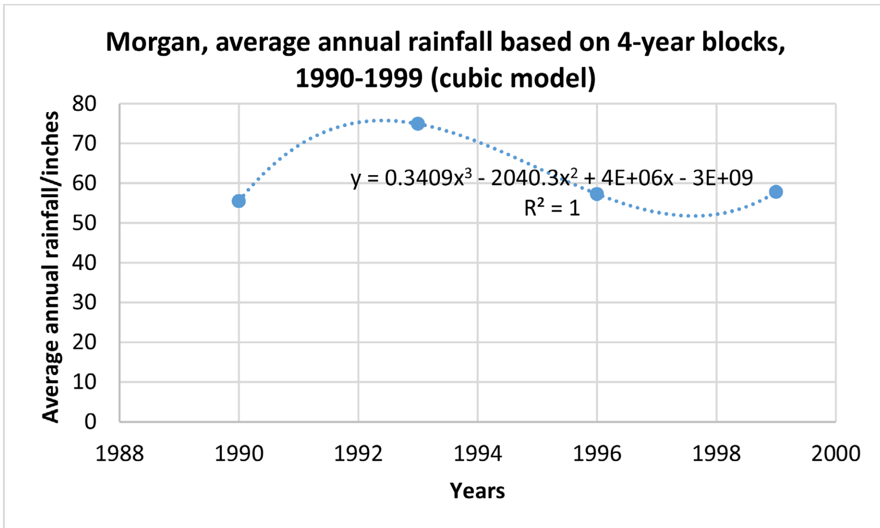

Figure 16. Model for rainfall Morgan (1990-1999).

The data for 1999-2017 was then fitted to a quadratic model that is presented in **Figure 17**.

The rainfall/4-year data for Morgan dropped from 60 inches in 1999 to about 47 in 2008 and then rose to 70 inches in 2017.

Prediction for Morgan's average annual rainfall for was carried out by extrapolation of the model that final general trend (2008-2017) to 2010. The predicted annual average rainfall was about 99.9 - 100.5 inches (**Figure 18**). The model explains 85% of the field data.

Rainfall of 100in is quite high. A better estimation for predicted rainfall was determined by using the data for 2005-2017 and then extrapolating the equation to 2030. The average of the two models was taken as the predicted magnitude of rainfall for 2030. **Figure 19** illustrates the model for 2005-2030 based on extrapolation of the data for 2005-2017. The predicted average rainfall by this model

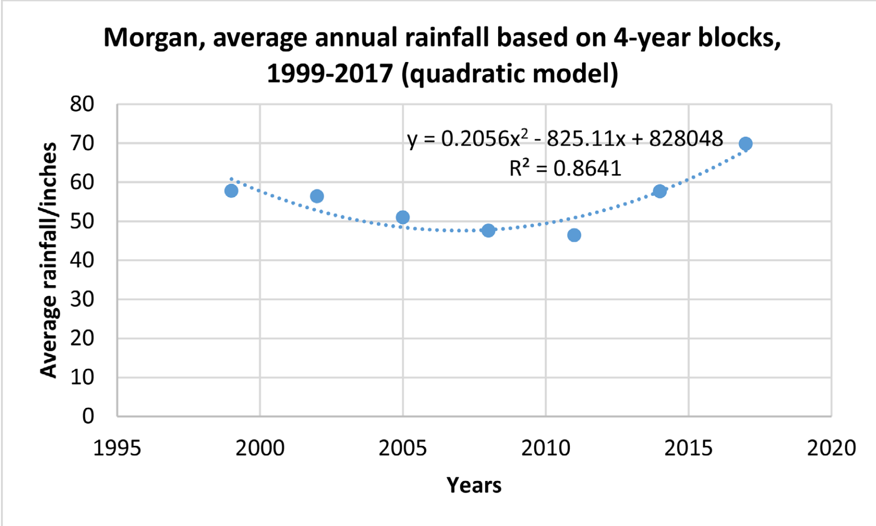

Figure 17. Model for rainfall data for Morgan (1999-2017).

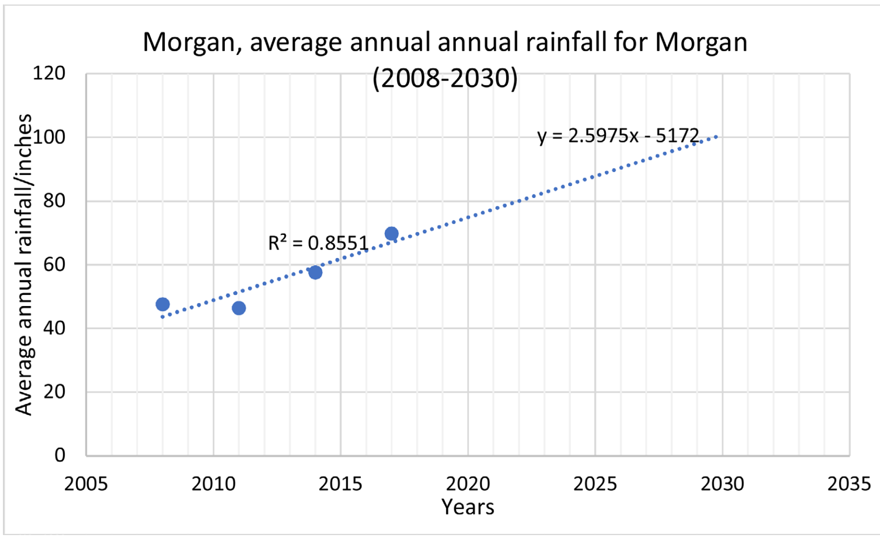

Figure 18. Model for average annual rainfall for Morgan (2008-2030).

was about 85 inches. Hence, a better model was determined by calculating the average of 100 in and 85 inches.

Predicted average annual rainfall = (100 + 85)/2 = 92.5 in.

3.3. New Orleans, Audubon

The average annual rainfall/4 years' data for New Orleans, Audubon, based on 4-year blocks is presented in Table 16.

The 1990-1999 average annual rainfall data for New Orleans, Audubon, was fitted to a cubic equation. A strong model of R squared equal to approximately 100% was obtained. It is presented in Figure 20.

As illustrated in Figure 20, the average annual rainfall for New Orleans, Audubon rose from about 51 inches to about 72 inches between 1992 and 1994. It then decreased gradually to a local minimum of about 47 in, and then rose to

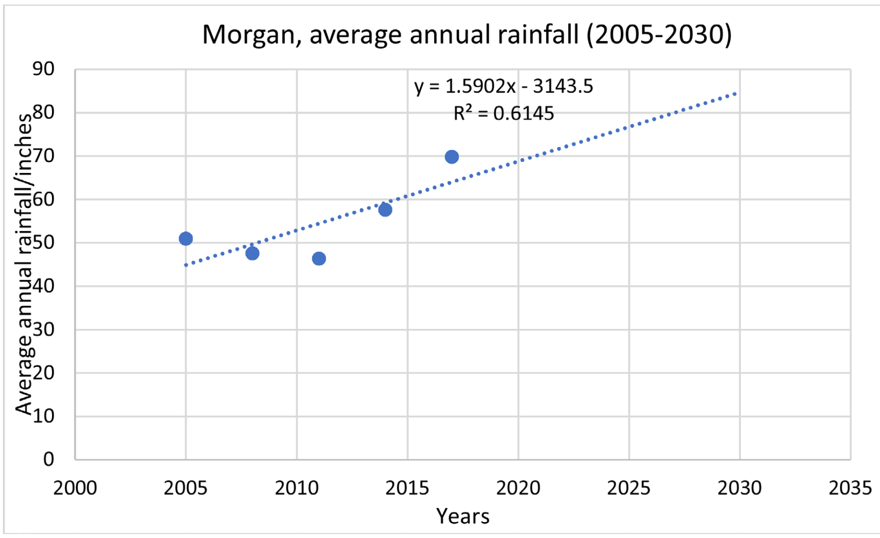

Figure 19. Model for average annual rainfall for Morgan (2008-2030).

Table 16. The average annual rainfall data for New Orleans, Audubon, based on 4-year.

Year	Average annual rainfall/4 years
1990	52.96
1993	71.92
1996	51.47
1999	56.5
2002	51.58
2005	61.51
2008	50.12
2011	51.96
2014	44.85
2017	41.26
2020	56.09

approximately 56.5 inches. The 1999-2008 average annual rainfall data for New Orleans, Audubon, was fitted to a cubic equation, yielding a strong model of R squared equal to approximately 100% (**Figure 21**).

The average rainfall fell from 56.5 inches in 1999 to 50 UNTS in 2001 and rose to 61.5 inches in 2005. It then dropped to approximately 50 inches in 2008.

Audubon's average annual rainfall data for 2008 to 2020 was fitted to a cubic model **Figure 22**. The model is given as, $y = 0.0844x^3 - 509.98x^2 + 1E + 06x - 7E + 08$, with $R^2 = 0.9994$. The model represents almost 100% of the variation in the data. Between 2008 and 2011, the average annual rainfall remained approximately at 50 in. It then decreased to a local minimum of approximately 40 inches and then rose to slightly above 55, 2020.

Prediction for New Orleans, Audubon's average annual rainfall for 2030 was

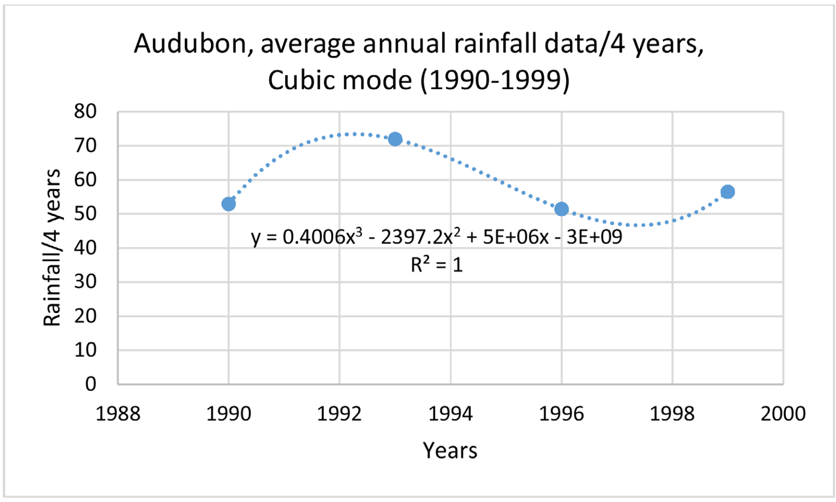

Figure 20. Average annual rainfall data for New Orleans, Audubon (1990-1999).

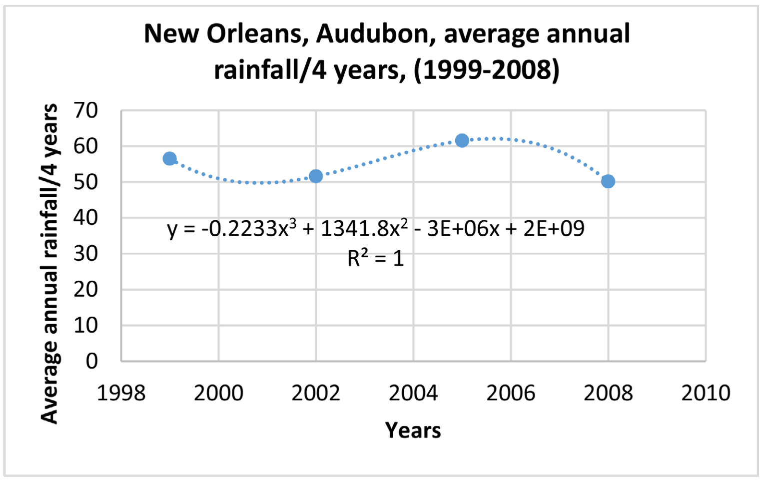

Figure 21. The average annual rainfall data/4 years for New Orleans, Audubon (1999-2008).

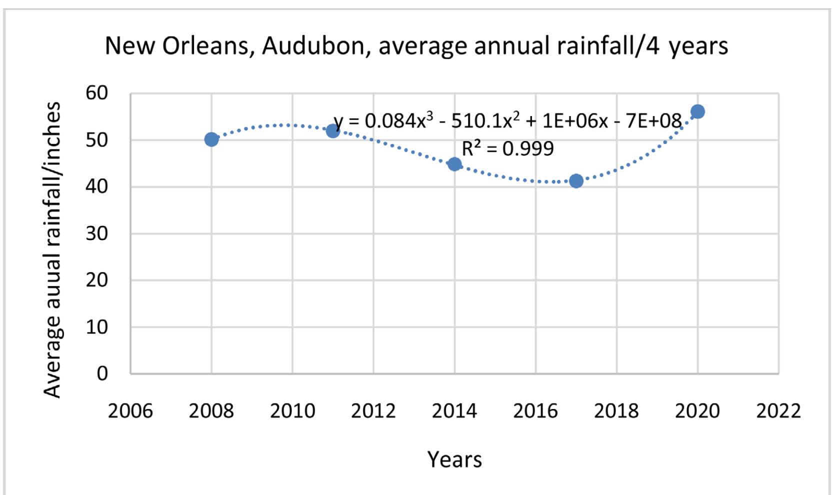

Figure 22. The average annual rainfall data/4 years for New Orleans, Audubon (1999-2008).

carried out by extrapolation of the linear model developed from modeling of the final three readings from the model for rainfall for the period 2008-2020. This section suggests an increasing trend. The predicted annual average rainfall for the year 2030 is about 72 inches (**Figure 23**). The model explains 53% of the field data.

3.4. Plaquemine, Iberville

Plaquemine's average annual precipitation 4-year basis data is presented in **Table 17**.

Its average rainfall data/4 consecutive years for 1990-2020 was fitted to a third order polynomial (**Figure 24**). This model represents 85.6% of the variability in Plaquemine's precipitation data. According to the model, the average rainfall per 4 years decreased along a gentle almost horizontal slope from the initial magnitude of approximately 60 inches in 1990, to approximately 57 inches in 2003. It then rose gradually to about 100 inches in 2020.

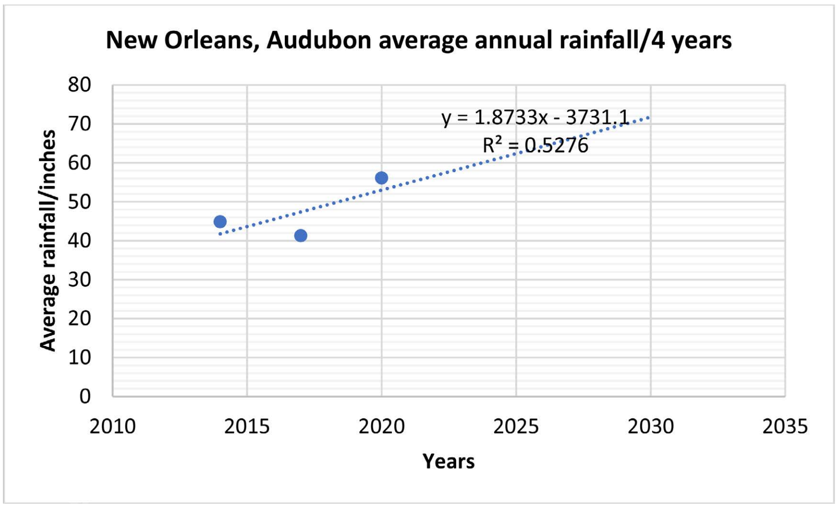

Figure 23. Model for average annual rainfall for New Orleans, Audubon (2014-2030).

Table 17. The average annual rainfall data for Plaquemine, based on 4-year.

Year	Annual average rainfall
1990	55.27
1993	69.1175
1996	63.1
1999	57.0225
2002	55.235
2005	58.87
2008	50.6425
2011	65.205
2014	70.3325
2017	91.89
2020	93.9125

Prediction for Plaquemine, Iberville's average annual rainfall for 2030 was carried out by extrapolation of the model that final general trend (1996-2020). The predicted annual average rainfall was about 109.7 - 108.8 inches (Figure 25). The model explains 74% of the field data.

3.5. Ponchatoula Data

The average annual precipitation data on 4-year basis for Ponchatoula is presented in Table 18.

The average annual precipitation per 4-year basis for Ponchatoula, Tangipahoa for 1990-1999 was fitted to a quadratic function (Figure 26). The model's R^2 was equal to 0.955. Hence, it represents about 95.5% of the variation in the data. The average annual precipitation rose according to a quadratic model (Figure 26) from

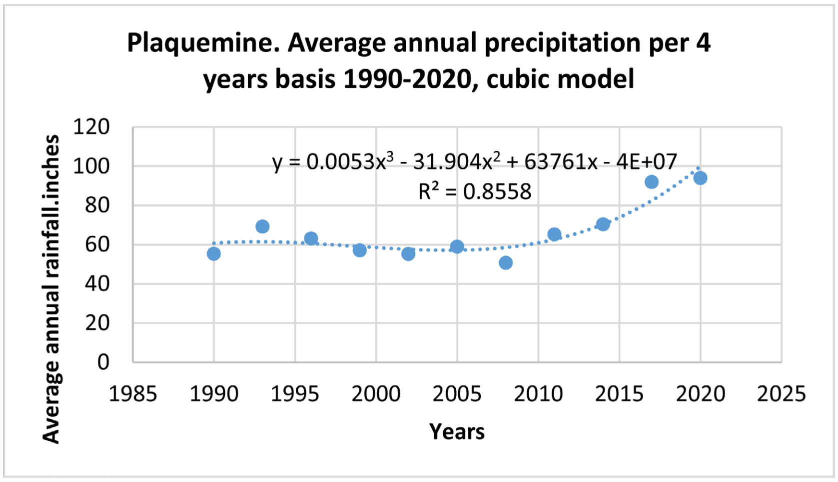

Figure 24. Plaquemine's average annual rainfall data/4 consecutive years versus years (1990-2020).

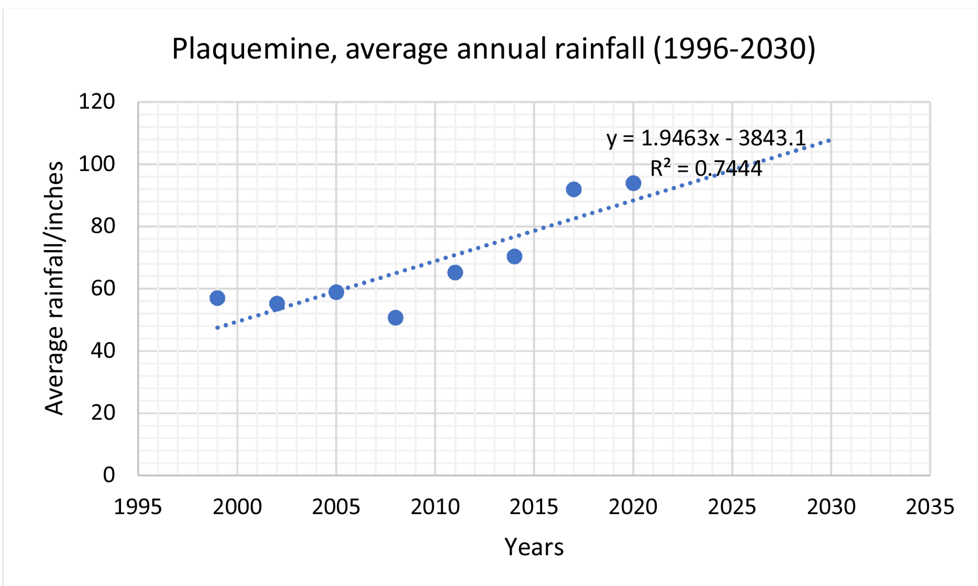

Figure 25. Model for average annual rainfall for Plaquemine (1996-2030).

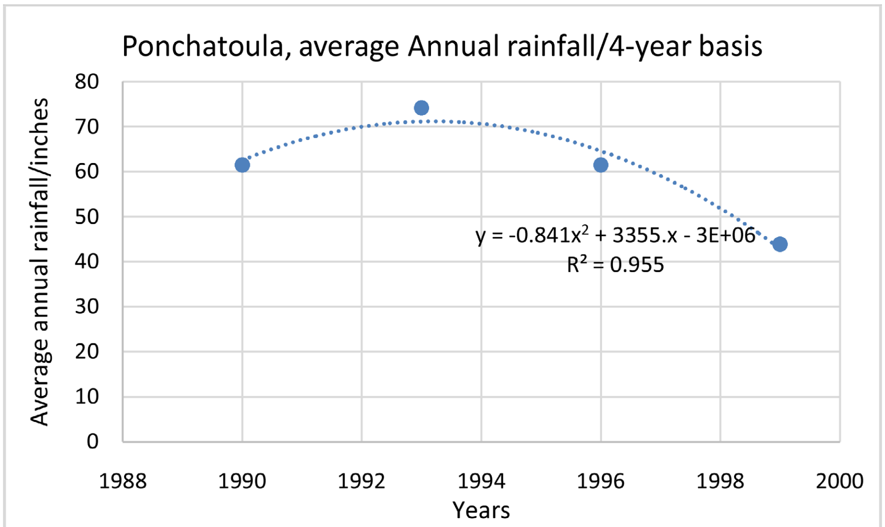

Figure 26. Average annual precipitation for Ponchatoula, Tangipahoa for 1990-1999.

Table 18. Average annual precipitation versus years' data on 4-year basis (Ponchatoula).

Year	Ave Annual rainfall
1990	61.52
1993	74.2
1996	61.52
1999	43.9
2002	71.49
2005	54.12
2008	59.44
2011	48.98
2015	78.6
2018	67.9

60 inches to about 70 inches in 1993 and then decreased gradually to approximately 43 inches in 1999.

For the period 1999-2008, a third-order polynomial model was used to fit the data. It is presented in Figure 27. The coefficient of correlation R^2 for this model was found to be 1. Hence, it represented about 100% of the data's variation.

The precipitation rose from 43.9 inches in 1999 to approximately 71 inches in 2002 and then dropped to a local minimum equal to approximately 50 inches in 2006. The rainfall then increased to 60 inches in 2008.

For 2008-2018, a third-order polynomial model was used to fit the data (Figure 28).

According to the model, precipitation decreased following a cubic function from 60 inches in 2008 to about 46 inches in 2010. It then increased to a maximum of 81 in and then decreased to about 69 inches in 2018.

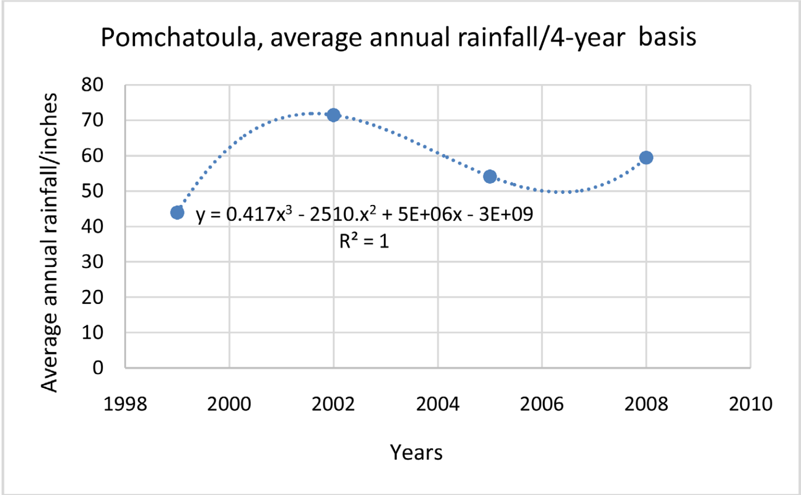

Figure 27. Average annual precipitation per 4 years basis for Ponchatoula, Tangipahoa (1999-2008).

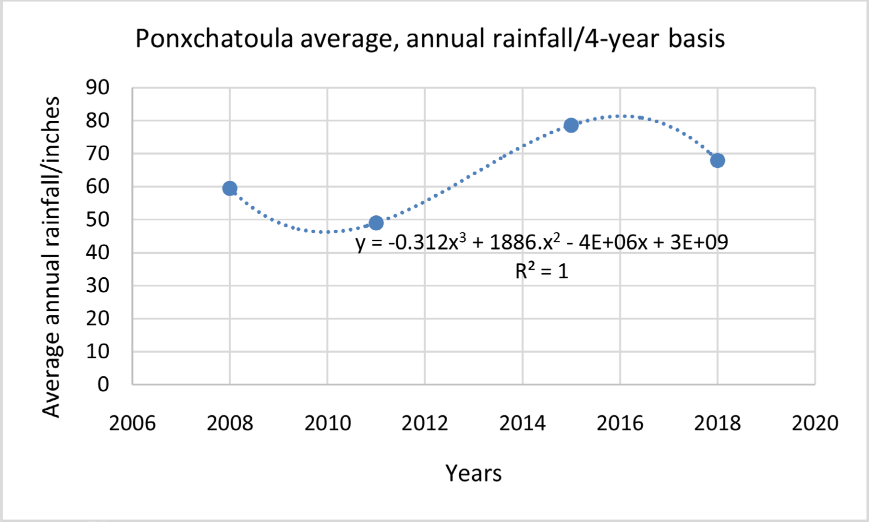

Figure 28. Average annual precipitation per 4 years basis for Ponchatoula, Tangipahoa (2008-2018).

Apart from studying the variation of rainfall on station basis, the variation of rainfall with respect to elevation was also modeled. Generally, stations that were far from the sea were expected to be in areas at the highest elevations above sea the level. The average rainfall for Southeastern Louisiana weather stations on a 4-year basis and corresponding area average elevations are presented in Table 19.

Table 19. Average rainfall for Southeastern Louisiana weather stations on a 4-year basis and corresponding area average elevations.

Elevation above sea level/feet	Average annual rainfall rain per 4-yearbasis/inches
3	53.6 on Page 25.5636
4	56.23561

Continued

25.9	62.167
10	61.8075
26.2	60.91273
22	57.41882
23	67.53275

A model for the variation of average rainfall with respect to average elevation of areas from which data was derived was carried out using Microsoft Excel. The model, representing 42% of the variation in the data is presented in **Figure 29**.

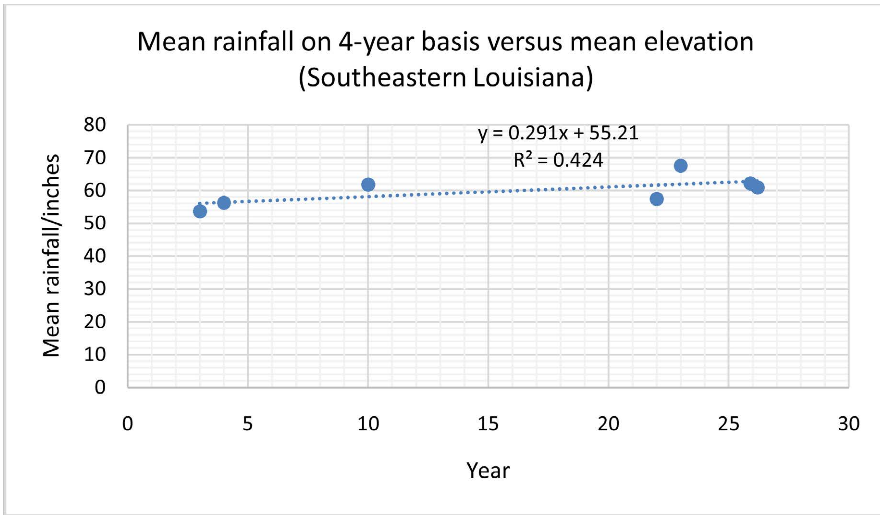

Figure 29. Model for the variation of average rainfall with respect to average elevation of areas represented by the stations.

Microsoft statistical tool to test the variation presented by the model was for statistical significance. The summary is presented in **Table 20**.

Table 20. Summary of model for the variation of average rainfall with respect to average elevation of areas represented by the stations.

SUMMARY OUTPUT					
Regression Statistics					
Multiple R	0.990332				
R Square	0.980758				
Adjusted R Square	0.971137				
Standard Error	0.971008				
Observations	4				
ANOVA					
	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	96.11429	96.11429	101.9394	0.009668
Residual	2	1.885714	0.942857		

Continued

Total	3	98						
	Coefficients	***Standard Error***	***t Stat***	***P-value***	***Lower* 95%**	***Upper* 95%**	***Lower* 95.0%**	***Upper* 95.0%**
Intercept	−182.686	19.78367	−9.23417	0.011525	−267.808	−97.5635	−267.808	−97.5635
54	3.314286	0.328261	10.0965	0.009668	1.901894	4.726678	1.901894	4.726678

Although the model represents 43.5% of the variation in the data, the summary (**Table 18**) it shows that it is statistically significant ($p < 0.05$). Since the gradient is positive, there was a general increase in average rainfall per 4 years as the average elevation above sea level increased.

4. Recommendations and Conclusions

This study revealed high variabilities in rainfall throughout the range of years considered. The major factors influencing variability in rainfall trends are global warming and climate change. The results and analyses found that Southeastern Louisiana has been experiencing rising and dropping rainfall patterns. However, the general trend was an increase for all stations. Apart from Plaquemine, all the other stations were expected to experience significant rainfall increases from 2011. Stations in areas of relatively higher elevations above the sea level tended to generally experience higher average rainfall.

Analysis of data collected during the last 6 years found a trend of increase in the average annual rainfall for the areas whose rainfall data was studied. The predictions for 2030 have also revealed a general precipitation increase in Southern Louisiana. The increase in precipitation is positively correlated with aerial and soil moisture. Since agriculture contributes significantly to the economy of Louisiana, research may have to be carried out to either maintain or boost the resiliency of the region's crops against gradual changes in soil and aerial moisture. Research on anticipated crop diseases and pastes, and invasive species associated with an increase in rainfall should be carried out so that stakeholders can be well prepared for possible their impacts on agriculture, forests, and wildlife.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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